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SUMMARY TALK AT THE INTERNATIONAL SYMPOSIUM ON STRANGENESS IN HADRONIC MATTER

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A selected summary of the workshop is presented. Emphasis is placed on the future role of studying kaon rare decay and an apparent solution of the $\Delta I = 1/2$ enhancement in strangeness-changing weak decays. Also discussed is a proposed kaon condensate of hadronic matter as well as recent and proposed experiments on $S = -1, -2$ dibaryons. The summary concludes with a brief discussion of the status of hypernucleus research.

1. INTRODUCTION

As recently as five years ago a workshop on strangeness convened by nuclear physicists would have been dominated by issues in hypernuclear physics. As a measure of how far our perspectives have grown, consider what we have explored this past week: hadronic structure, the decays and interactions of hadrons, the high-density, high-temperature behavior of hadronic matter, extensions of the Standard Model as well as hypernuclear physics. This increased range of interests results from strong common themes that extend over a wide variety of physics. The organizers of this conference have done a superb job in utilizing the concept of strangeness to knit together a seemingly diverse body of phenomena, and ^{have} produced an excellent and stimulating week.

To obtain a sense of what was covered, let's look at Fig. 1, which depicts the fundamental interactions as a function of increasing energy, decreasing distance, and presumably greater unification. The dotted line in Fig. 1 refers to the range of demonstrated applicability of the Minimal Standard Model (MSM). The hadronic sector is not included, as it is not clear that $SU(3)$ QCD has demonstrated applicability in that sector. The most intensively discussed region of this diagram was along the strong interaction line in both the meson-baryon and quark-gluon sector of the MSM. Table I is an outline of the subject matter that was discussed.

* Work performed under the auspices of the US Department of Energy.

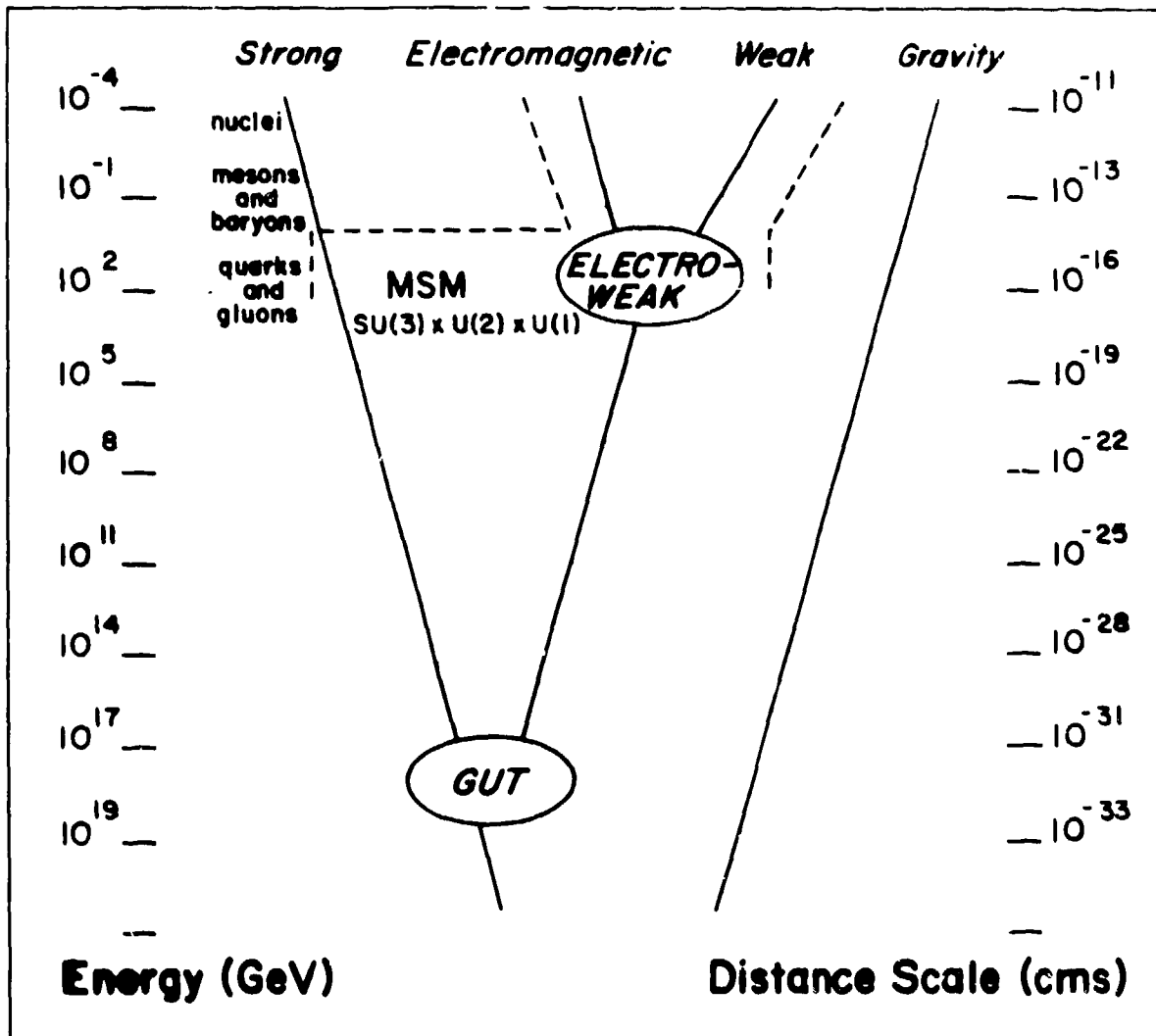


FIGURE 1
Diagram of fundamental interactions.

The strangeness flavor is carried by the strange quark. It has charge $|\frac{1}{3}e|$ and is found as a constituent of both mesons and baryons. The lightest strange meson is the kaon ($m_k \cong 500$ MeV), whereas the lightest strange baryons are the Λ , ($m_\Lambda \cong 1116$ MeV), and the Σ ($m_\Sigma \cong 1190$ MeV). The fact that the K^0 ($d\bar{s}$), with strangeness = 1, and the \bar{K}^0 ($\bar{d}s$), with strangeness = -1, differ by two units of strangeness and seemingly mix gives rise to a host of unique phenomena, the most fundamental being CP violation.

2. SUMMARY

Time will permit me to only touch on a few subjects presented during the week and I will select the material with the bias of an experimentalist. However, that disclaimer cannot permit me to ignore the apparently outstanding contribution of Buras, Gerard, and Bardeen in accounting for the long-standing problem of the $\Delta I = 1/2$ enhancement in the hadronic weak decay of strange particles.

TABLE I^a
PHYSICS WITH STRANGENESS

Hadron Structure

- Role of strange sea quarks in nonstrange systems.
- Flavor dependence of hadronic radii.
- $|S| = 1, 2$ dibaryons.

Hadronic Interactions

- Electroproduction of strangeness.
- Diffractive production of strangeness.
- $p\bar{p}$ production of strangeness.
- Hypernuclear physics.
- $Y-N$, $Y-Y$ interactions via meson exchange, via QCD degrees of freedom.

Strange Hadronic Matter

- Baryon number = 0 quark-gluon matter.
- Relativistic heavy-ion collisions.
- Baryon number $\neq 0$ quark-gluon matter.
- Equation of state at high temperature and pressure, kaon condensation, strange quark matter, astrophysics, strangelets.

Electroweak Processes with Strange Hadrons

- Weak decay of strange hadrons, $\Delta I = 1/2$ enhancement.
- ϵ'/ϵ and CP violation in the K^0 system.
- $B^0\text{-}\bar{B}^0$ systems.

Beyond the Standard Model

- Rare K decays.

^a Topics presented and discussed at the symposium.

In these decays the $\Delta I = 1/2$ amplitude shows an enhancement of 10–20 over the $\Delta I = 3/2$ amplitude. For several years QCD calculations¹ have struggled with the problem but could not achieve sufficiently large enhancement. Earlier work has identified the necessary diagrams but part of the calculation necessarily requires dealing with quark momenta in the nonperturbative regime of QCD. Burras reported that he and his colleagues have used QCD to account for virtual processes above 1 GeV and employ a hadronic representation below 1 GeV. Much of the $\Delta I = 1/2$ enhancement comes from this hadronic regime. The specific problem they have calculated is the ratio of the amplitudes for

$$\frac{K_L^0 \rightarrow \pi^+ \pi^-}{K^+ \rightarrow \pi^+ \pi^0}$$

The numerator is dominated by $\Delta I = 1/2$ while the denominator is pure $\Delta I = 3/2$. The experimentally determined ratio is 15 while they calculate 12 ± 1 . This has to be regarded as a major triumph for the Standard Model as there was some question as to whether the $\Delta I = 1/2$ enhancement could be obtained without new physics. Of course, assuming they have solved the problem without new physics assumes that the hadronic sector is ultimately obtainable from QCD.

Very similar diagrams enter the calculation of the parameters characterizing CP violation in K decay. Using techniques similar to those described above, Buras and his colleagues find $\epsilon'/\epsilon = 2.0 \times 1.0^{-3}$ with a top quark mass of 40 GeV and $\epsilon'/\epsilon = 1.5 \times 1.0^{-3}$ for $m_T = 55$ GeV. Because of their success in calculating the $\Delta I = 1/2$ enhancement, there are grounds for believing that these small values of ϵ'/ϵ are the correct values obtained with the MSM. These values are quite compatible with existing measurements of ϵ'/ϵ . It is now up to experimentalists to push the measurements of ϵ'/ϵ down to and below the 0.1% level.

Kleinknecht presented a very excellent summary of the experimental status of CP violation in K decay and searches for rare K decays. He reported the most recent result for ϵ'/ϵ from Winstein and collaborators at FNAL as $\epsilon'/\epsilon = 0.0035 \pm 0.003 \pm 0.002$, an even more precise result may be forthcoming soon from NA 31 at CERN. Thus, the requisite accuracy for testing if the origin of CP violation in K decay lies within the Standard Model is coming near to hand. A most interesting part of his talk was presentation of the evidence² for strong b flavor mixing in the B^0, \bar{B}^0 system. It appears that the flavor mixing may be 100 times that in the K^0, \bar{K}^0 system. Hence, CP violation in that system may be much larger, and the opportunity to increase our understanding of flavor mixing due to weak interactions in the quark sector is greatly enhanced. Among the rare decay experiments discussed by Kleinknecht was E791 at BNL which is searching for the forbidden decay, $K_L^0 \rightarrow \mu e$ with sensitivity greater than 10^{-11} . The experiment uses two magnets to suppress the undesirable background arising from $K^0 \rightarrow \pi e \nu_e$. Resolution the order of 1 MeV is required to achieve the desired sensitivity. At a branching-ratio sensitivity of 10^{-11} , the experiment explores possible lepton family-changing boson masses on a scale of 100 TeV!

Even though the branching ratios (BR) for a rare decay is only sensitive to the inverse fourth power, the mass of a lepton family-changing boson (see Fig. 2)

$$\text{BR (forbidden decay)} \sim \left(\frac{G_B^2}{q^2 + M_B^2} \right)^2 \left(\frac{q^2 + M_W^2}{G_W^2} \right)^2, \quad (1)$$

where $q^2 \ll M_W, M_B$, these measurements are and will continue to be powerful probes for searching out new physics. One might believe that searches for rare decays would fall behind direct investigations employing higher and higher accelerator energy. This is not the case. An examination of the rate of increase of accelerator energy shows an order of magnitude increase every 12 years.

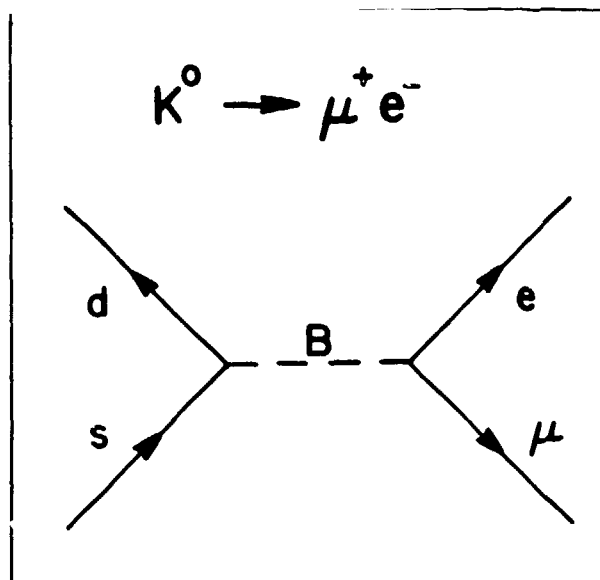


FIGURE 2
Feynman diagram for $K^0 \rightarrow \mu e$ via a
flavor-changing neutral gauge boson.

Figure 3 shows that sensitivity of searches for rare decays of the muon gains a factor of 10 approximately every 3 years. Hence, in terms of the mass scales being investigated, these two technologies are keeping pace with one another. Of course, the experiments become increasingly more difficult (i.e., expensive). The reason that the rare decay searches can remain apace arises from the multidimensional nature of detectors. Improved energy, momentum, and timing resolution allow better suppression of background while faster electronics, parallel processing, and increased beam currents allow both sufficient production and coping with the high rates necessary to investigate ever smaller branching ratios.

H. Harari³ has pointed out a real difficulty in continuing to carry out the search for new physics by going to ever higher beam energy. The cross sections for creating a new pointlike boson via the collision of point particles goes as $1/Q^2$. At FNAL, 2 TeV is now available; hence in about 36 years we might expect 10^{15} eV (1 PeV). The cross section for creating a new point like object at that energy is 10^{-43} cm². To observe 10^3 events in a year would require a beam luminosity of 10^{39} cm⁻² s⁻¹. If the beam flux is not increased beyond what is presently foreseen, a beam diameter of 10^{-8} cm is required in the interaction region. Thus rare decay continues to appear as a promising, effective, and competitive way to seek out higher mass scales independently of accelerators going to higher and higher beam energies.

Many of the talks at this workshop dealt with properties of strange hadronic or strange quark matter. Unfortunately, these talks were restricted primarily to theoretical consideration, and only the bravest tried to establish where the point of contact with observation might exist. Gordan Baym gave a very nice discussion of

the problem using general thermodynamic arguments and a simple quark-gluon model for the high-temperature nuclear medium. He further made simple but convincing arguments that for a quark-gluon plasma with finite baryon density the ratio of $\bar{\Lambda}/\bar{p}$ would be enhanced as u , \bar{u} , d , and \bar{d} quarks are suppressed due to the Pauli principle because they are present in nucleons. Similarly, we would expect to see $\bar{s}q$ enhanced over $s\bar{q}$ in the meson spectrum. A fascinating aspect of this physics is a speculation⁴ of Baym and his coauthors on the origin of the surplus muons observed in higher-energy cosmic-ray showers that apparently originate from point sources. To understand the issues the following background discussion is presented.

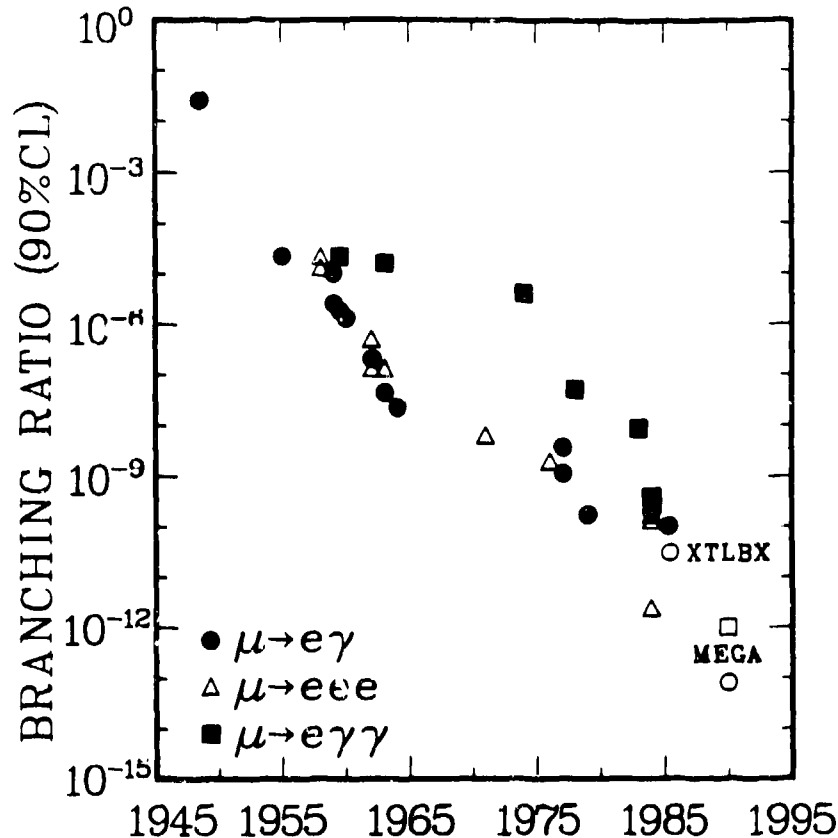


FIGURE 3
Plot of the upper limits achieved in previous rare muon decay, plus the sensitivity of proposed experiments.

There are presently operating around the world a few scintillator arrays at ground level⁵ looking for pointlike sources of very high energy ($E > 10^{14}$ eV) cosmic rays. Because of the vast distances and high energies involved one needs to realize a few crucial relationships. The radius of a curvature ρ [in light years (LY)] of a charged particle in space due to intergalactic magnetic fields ($H_{IG} \cong 10^{-6}$ G) is

$$\rho \text{ (LY)} = \frac{3P \text{ (PeV)}}{H_{IG} \text{ (}\mu\text{G)}} \quad (2)$$

Thus as the sources being studied are 10^4 – 10^5 light years away and the particle energies are the order of 1 PeV, the orbits would be completely scrambled if the

cosmic rays initiating the air showers were charged. Thus if one sees cosmic-ray showers originating from a point source, the cosmic ray initiating the shower must be neutral. The characteristic distance traveled by a particle with a proper lifetime τ_0 before it decays is

$$d \text{ (LY)} = \tau_0(Y)c\gamma . \quad (3)$$

Hence a PeV neutron traverses some 33 light years before decay. The incident flux of neutral particles observed from distant sources would therefore require a longer-lived neutral object than the neutron.

The signals associated with these point sources seem to occur with a regular period associated with pulsar frequency. If the initiating cosmic ray has a large rest mass (M), there would be a dispersion of their arrival times (Δt) caused by variation in their total energy (E). An upper limit on their mass can be set due to the observed lack of dispersion in arrival times,

$$M \text{ (GeV)} \leq \sqrt{\frac{\Delta t \text{ (s)}}{D \text{ (LY)}}} \frac{E_1 E_2}{E^2 - E_1^2} \text{ (PeV)} \approx 2.5 \times 10^2 . \quad (4)$$

The observed particle energy varies from 0.1 to 1 PeV. The arrival times are synchronized to within 10^{-3} s for Herc X-1, which is 15×10^3 LY distant (D). This yields an upper bound on the mass of the object of 6.5 MeV.

This latter limit on the mass was not known at the time that Baym and coworkers speculated⁴ that the high-energy neutral particle might be neutral pieces of relatively stable strange quark matter with sufficient lifetime to reach the earth. A long-lived Λ dibaryon is a candidate. Such a piece of matter would be able to account for the large number of muons observed in the high-energy showers caused by these high-energy neutral particles. The limit on the mass cited above, however, rules out any known or conjectured hadronic object, leaving the photon as the most likely candidate. This choice, however, creates a problem with respect to the large number of muons that are observed in the shower. This is very exciting and may be showing the way to new physics.

A new and interesting development that was very well covered in the conference is the possibility that a kaon condensate might occur not too far beyond normal nuclear density ($\sim 3.4\rho_0$). While much interest over the past decade has focussed on the properties of strange quark matter⁶ the version of kaon condensation reported on by Kaplan and Nelson follows entirely from hadronic degrees of freedom and is similar to an earlier conjectured pion condensate. This work which was first published⁷ about one year ago by Kaplan and Nelson is rooted in $SU(3) \times SU(3)$ chiral perturbation theory. It is sometimes referred to as the nonlinear sigma model and has been developed by Weinberg,⁸ and Manohar and Georgi,⁹ among many others. Kaplan did an excellent job in explaining the elements of chiral

perturbation theory which is an expansion in power of the relevant masses and dynamical variables over the chiral-breaking parameter Λ ($\Lambda \sim 1$ GeV), i.e.,

$$\frac{p^2}{\Lambda^2}, \quad \frac{E^2}{\Lambda^2}, \quad \frac{m_\pi^2}{\Lambda^2}, \quad \text{and} \quad \frac{m_K^2}{\Lambda^2} .$$

The condensation comes about because of a kaon-baryon interaction of the form

$$\bar{H} = -m_K^2 |K|^2 \cdot B\bar{B}/n \text{ crit} . \quad (5)$$

At high baryon density the effective kaon mass is reduced by a factor depending on $n/n \text{ crit}$. This leads to $(m_K)_{eff}^2 = m_K^2(1 - n/n \text{ crit})$, and kaon condensation occurs at the baryon density $n = B\bar{B} = n \text{ crit}$.

Chiral perturbation theory requires phenomenological input to fix the various coefficients in the Hamiltonian. A very important coefficient is determined by the so-called pion-nucleon sigma term. It is a measure of the chiral symmetry breaking in low-energy pion-nucleon scattering brought about by quark mass terms. A large pion-nucleon sigma term translates to an even larger kaon-nucleon sigma term because of the larger masses involved. Unfortunately, it is very difficult to directly extract a value for Σ_{Kn} from kaon-nucleon scattering. The very large s -wave coupling between the kaon and nucleon that is inferred from the pion-nucleon system is largely responsible for kaon condensation at relatively low values of the baryon density ($3.7 \rho_0$).

While the theoretical argument for a kaon condensate seems plausible, it is by no means clear how it might be observed in the laboratory. Ann Nelson discussed a variety of possibilities in her talk; the most interesting was the possibility that in a heavy-ion collision conditions might be achieved that would cause a kaon condensate. The K^- and \bar{K}^0 are strongly coupled to nucleons and can readily be adsorbed to yield Λ 's and Σ 's, whereas the K^+ , K^0 with a much weaker coupling (see Fig. 4) are ejected. Hence a very large increase in the K^+ and K^0 might be a signature of formation of a kaon condensate. This emission would leave behind a system with a very large value of negative strangeness whose subsequent decay would also be very amusing. Many of the presentations on relativistic heavy-ion collisions that produced high-temperature baryon-rich systems predicted that enhanced K^+ emission would be expected for presumably similar reasons, thus it looks like an interesting channel to investigate.

Turning to somewhat more conventional physics, the discussion of strange dibaryons was considerably freer of speculation. Piekarczyk reported on two possible $S = -1$, $B = 2$ states near the $p\Lambda$ threshold. They are

$$L = 0 \quad M = 2131.8 \pm 1.5 \text{ MeV} \quad \Gamma \sim 25 \text{ MeV} ,$$

$$L = 1 \quad M' = 2141.3 \pm 1.2 \text{ MeV} \quad \Gamma' \sim 25 \text{ MeV} .$$

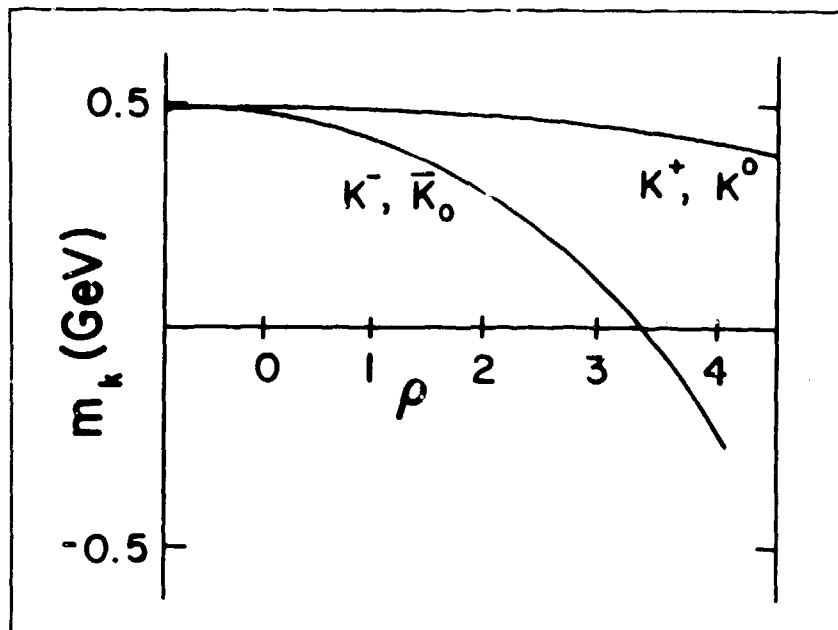


FIGURE 4
Schematic plot of the effective mass of kaons as a function of baryon density in units of the normal nuclear density.

He also reported that similar resonances have been observed by Seibert et al. at Saclay in the $P + P \rightarrow K^+ X$ reaction. The incident proton energy was 2.3 GeV.

Perhaps even more interesting is the $S = -2$, $B = 2$ system. Fassler presented some very interesting theoretical results that predict this system to be bound by approximately 20 MeV. There have been a wide variety¹⁰ of calculations for this most symmetric six-quark ($uuddss$) system. Unfortunately, the calculations vary by a GeV in the predicted mass, but several of them suggest that the H is bound against strong decay. There are a variety of experiments proposed to measure this system. At the AGS, Barnes and Franklin proposed to produce the H particle via either of two processes. The first is a one-step reaction

$$K + {}^3\text{He} \rightarrow K^+ + H + n$$

or a two-step process

$$K^- + p \rightarrow K^+ + \Xi^-$$

and

$$\Xi^- + d \rightarrow n + H .$$

In this latter process, the neutron kinetic energy reveals the mass of the H as the Ξ^- is thermalized and captured from an "atomic" orbit. This scheme is clearly limited by available K^- flux and the branching ratio for H formation in the second step is very difficult to calculate. A suitable beam line to try these experiments may be available

at the AGS in 2-3 years time. At FNAL, Piekarczyk proposes to study the H by diffractive production and subsequent diffractive dissociation. The incident beam is to be 200 GeV/c protons, which are to produce forward-going H 's. The H passes through a veto counter into active dissociators, which causes the H to fragment into a $\Lambda\Lambda$ pair that is subsequently detected as two $p\pi$ pairs. In my opinion, this system might allow one to show that a bound H particle exists as a bound neutral state; however, it is not clear how this process will measure its mass because of the disrupting nature of the Pomeron responsible for the dissociation. I understand Povh and Schlein also propose to study the $S = -2$, $B = 2$ system at CERN via study of the diffractively produced $\Lambda\Lambda$ pairs.

The lack of good-quality K^- beams has greatly attenuated the study of hypernuclei. The most interesting recent results were presented by Peter Barnes. He reported on measurements of the weak decay of some light hypernuclei. Recall that in a hypernucleus, the decay may proceed in the manner similar to the free decay ($\Lambda^0 \rightarrow p\pi^-$, $n\pi^0$) with an emitted meson or via the process $\Lambda N \rightarrow NN$. The mesic decay is strongly Pauli suppressed, and this suppression will increase with atomic number. The hypernucleus lifetime is determined by the contributions of all of the above processes. We now have measurements on ${}^5\text{He}_\Lambda$, ${}^{11}\text{B}_\Lambda$, and ${}^{12}\text{C}_\Lambda$. The measured lifetimes are $\tau({}^5\text{He}_\Lambda) = 256 \pm 26 \times 10^{-12}$ s. This is 0.97 ± 0.08 times the free Λ lifetime, while $\tau({}^{11}\text{B}_\Lambda) = 192 \pm 22 \times 10^{-12}$ s and $\tau({}^{12}\text{C}_\Lambda) = 211 \pm 31 \times 10^{-12}$ s,¹¹ showing a tendency to fall below the free Λ lifetime. This, of course, is due to the larger role being played by the nonmesic decay mode. One of the most interesting aspects of this research is the opportunity to isolate $\Delta I = 3/2$ and $\Delta I = 1/2$ weak decays in the purely baryonic mode by comparing the $\Lambda n \rightarrow n + n$ to the $\Lambda p \rightarrow p + n$ modes. Isolating the separate isospin channels would allow investigation of the $\Delta I = 1/2$ enhancement, which at present is seen only in final states containing mesons.

The research reported on above was the bright spot among new experimental results on hypernuclear research. There were several excellent review talks on the earlier seminal work done with the (K^-, π^-) reaction at CERN and the AGS. Unfortunately, these laboratories have had other priorities over the past few years, so there has been little availability of kaon beam for hypernucleon research. About 18 months ago¹² it appeared that (K^-, π^\pm) reactions initiated by stopped kaons would be most useful, especially (K^-, π^+) for the study of Σ^- hypernuclear states. There appeared to be clear evidence that these states were quite narrow, and it posed an interesting puzzle to account for this apparent narrow width. Recall that the Σ is some 80 MeV more massive than the Λ , and one would expect the strong-interaction $\Sigma N \rightarrow \Lambda N$ to cause the states to be broad due to spreading and decay width. Apparently, further research at KEK by Heidelberg, the University of Tokyo, and INS have failed to confirm the earlier results¹² obtained at KEK. Though there are some differences

in the analysis, there remains at most, one identifiable peak in the $^{12}\text{C}(K^-, \pi^+)^{12}\text{B}_\Sigma$ -spectrum. This unfortunate turn of events removes what had been thought to be a new mode for the study of Σ hypernuclei, and raises the question about the existence of narrow Σ states, as there is now only a single confirmed example in $^{12}\text{B}_\Sigma$. If this subject is to continue to absorb our attention, new tools are required. Perhaps the (π^-, K^-) reaction will provide new and useful spectra. Failing this, one will be forced to use (e, e', K) or (γ, K) reactions at the new generation of CW electron accelerators. It is certainly a field where the existence of a "kaon factory" would have an enormous impact.

3. CONCLUDING REMARKS

In the course of this meeting there appeared two interesting cases wherein three quantities seemed to be related, though at the present moment we see no reason why they should be. The first was brought to our attention earlier this week by M. Rho, who pointed out that $m_s \sim \Lambda_{\text{QCD}} \sim T_c$. Why should the mass of the strange quark, the QCD scale parameter, and the critical temperature for formation of the quark-gluon plasma (restoration of chiral symmetry) be roughly equal? At the moment this coincidence seems to be fortuitous, but I had the distinct feeling that Rho did not. The second triplet deals with mysteries in the scalar sector of the strong interaction with vacuum quantum numbers $S = 0$, $B = 0$, $T = 0$, $J = 0$. At low energy the scalar part of the $T = 0$ nucleon-nucleon interaction is ascribed to a sigma meson. This "state" is thought to exist at 500–600 MeV and to be extremely broad. It is further believed to be a two-pion state. In high-energy reactions there is a bland object responsible for diffractive dissociation. It is referred to as a Pomeron, but there is little to characterize it save its flavorless, spinless nature in a virtual state. Many theorists have a strong belief that glueballs should exist and that the lowest mass glueball will carry the quantum numbers indicated above. Are these objects all one and the same? It is surprising to me how much of our ignorance is tucked away in this scalar-flavorless channel. Vigorous research on this problem might reveal some very interesting underlying unity in our description of strong-interaction processes. It appears to me that much could be learned from a study of $\pi^- + p \rightarrow n + X$, isolating the s -wave part of X and study it as a function of q and ω .

In closing, I want to observe that this was a conference in which there was a great breadth of material presented, but on the whole there was not much new experimental information. This meeting was driven by new theoretical developments bearing on new and exciting possibilities that emerge when our description of strongly interacting systems is extended to include strangeness. These possibilities include kaon condensates, altered behavior of quark-gluon plasmas, strange dibaryons, and strangeness as a probe of confinement inside normal nuclei. The observation of these phenomena and

their incorporation into theory will extend our understanding of many-body systems and astrophysics, as well as indicate how QCD works in the low-momentum regime.

However, observing these new phenomena requires new facilities and capabilities. New multi-GeV CW electron accelerators, relativistic heavy-ion facilities, as well as kaon factories with the order of 100 times the intensity available today, are required to make progress in a timely fashion. One should not have to wait more than a decade to experimentally investigate an idea as well motivated and accessible as a possible bound $S = -2$ dibaryon. This idea was first¹⁰ put forth in 1977, and there will likely not be any sensitive directed tests until 1990.

REFERENCES

- 1) For example, A. Pich, B. Guberina, and E. DeRafael, *Nucl. Phys.* **B277** (1986) 197.
- 2) H. Albrecht et al., *Phys. Lett.* **B192** (1987) 245.
- 3) H. Harari, SLAC-PUB-4223 (February 1987).
- 4) G. Baym, R. Jaffe, E. W. Kolb, L. McLerran, and T. P. Walker, *Phys. Lett.* **B160** (1985) 181.
- 5) R. J. Protheroe Rapporteur talk at the 20th International Cosmic-Ray Conference, Moscow, USSR, August 1987 (to be published by IUPAP).
- 6) Edward Farhi, *Comments Nucl. Part. Phys.* **16** (1986) 289.
- 7) D. B. Kaplan and A. E. Nelson, *Phys. Lett.* **B175** (1986) 57.
- 8) S. Weinberg, *Phys. Rev. Lett.* **17** (1966) 616, and **18** (1967), 188 and 507.
- 9) A. Monohar and H. Georgi, *Nucl. Phys.* **B234** (1984) 189.
- 10) R. L. Jaffe, *Phys. Rev. Lett.* **38** (1977) 195; A. P. Balachandra, *Phys. Rev. Lett.* **52** (1984) 887; and P. B. MacKenzie and H. B. Thacker, *Phys. Rev. Lett.* **55** (1985) 2539.
- 11) R. Grace et al., *Phys. Rev. Lett.* **55** (1985) 1055.
- 12) T. Yamazaki et al., *Phys. Rev. Lett.* **54** (1985) 102, and *Nucl. Phys.* **A450** (1986) 1C.